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Photochemical Oxidents in Yonkers, New York Effects on Yield of Bean and Tomato

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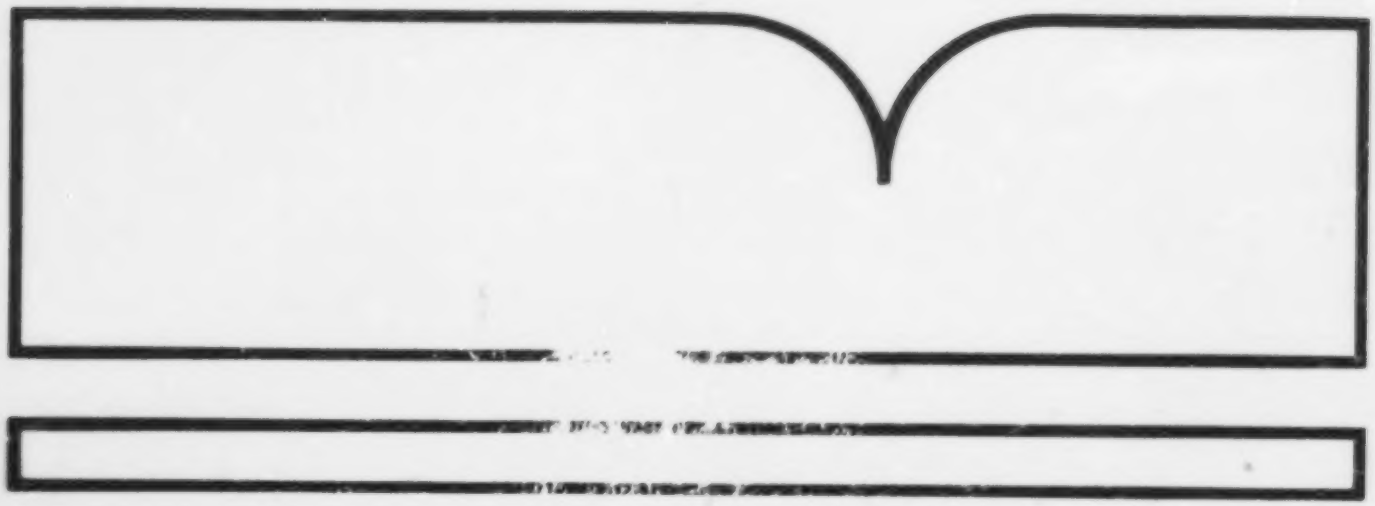

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Photochemical Oxidants in Yonkers, New York: Effects on Yield of Bean and Tomato[1]

D. C. MacLean and R. E. Schneider[2]

ABSTRACT

Field plots of bean (*Phaseolus vulgaris* L. cv. Tendergreen) and tomato (*Lycopersicon esculentum* Mill. cv. Fireball 861 VR) were enclosed in chambers and exposed for 43 or 99 days, respectively, to ambient air or to air from which 60 to 70% of the ambient photochemical oxidants were excluded. Comparisons between these treatments revealed that ambient oxidants at Yonkers, New York reduced the fresh weight yield of tomato by at least 33%, and in bean, the weight and number of marketable pods were reduced by 26 and 24%, respectively.

Additional Index Words: *Lycopersicon esculentum, Phaseolus vulgaris,* ozone.

Photochemical oxidants are the most ubiquitous phytotoxic air pollutants in the United States (12). The more common members of this class of pollutants, ozone (O_3) and the peroxyacyl nitrates (PANs), are formed by a series of sunlight-initiated reactions involving hydrocarbons and nitrogen oxides. Although this complex of gaseous pollutants is frequently found in urban atmospheres, its presence may extend over suburban and rural areas as well (15, 21). The adverse effects of oxidants on vegetation are both serious and widespread. Benedict, Miller, and Olson, (2) have estimated that losses to forest, horticultural, agronomic, and ornamental crops in the United States are more than $120 million annually, which is about 90% of all crop losses estimated to be caused by air pollution. Ozone is probably responsible for more plant injury than any other air pollutant (10, 12), and of the PANs, peroxyacetyl nitrate (PAN) is the most abundant and has received the most attention (27).

The occurrence of photochemical oxidants in the New York metropolitan area has been well documented (3, 6, 14, 15, 25). Over a period of 5 years, relatively high concentrations have been monitored during the summer months at Boyce Thompson Institute and foliar lesions have been found on oxidant-susceptible species (14). Several investigators (9, 11, 17, 24, 28, 29) reported that crop yields are undoubtedly reduced by exposures to ambient photochemical oxidants, but no quantitative data have been published on the yield of field-grown crops where continuous measurements of ambient oxidant concentrations were summarized and reported.

The development of field fumigation chambers, equipped with charcoal filters capable of excluding ambient oxidants (8, 20), permits long term field studies of growth and yield in which plants grown in atmospheres containing oxidants can be compared with plants grown in air from which most of the oxidants have been excluded. The effects of ambient photochemical oxidants on the yield of two vegetable crops were studied during the summer of 1973 and are described in this paper.

MATERIALS AND METHODS

Seeds of bean (*Phaseolus vulgaris* L., cv. Tendergreen) were sown and 5-week old tomato seedlings (*Lycopersicon esculentum* Mill. cv. Fireball 861 VR) were transplanted into six circular field plots. Each plot consisted of five tomato plants and five rows of bean. The bean rows were 1.3 m long with 18 plants per row arranged along isogonal radii from the center of the plot. One tomato plant was located in the center of the five sectors formed by the bean rows such that each was $\geqslant$0.5 m from the nearest bean plant or the edge of the plot. Two plots were enclosed with cylindrical, open-top field fumigation chambers equipped with activated charcoal filters to remove most of the ambient photochemical oxidant pollutants from the incoming air (20), and two were enclosed with chambers in which the incoming air was not filtered through charcoal. The two remaining plots were maintained as unenclosed controls.

Oxidant concentrations in filtered and unfiltered air were measured continuously throughout the experiment using the coulometric method (i.e., Mast Ozone Meters calibrated against KI and modified for continuous operation [19]). The sampling probes were located in the center of the chambers 1 m above the soil surface.

The bean plants were exposed to filtered or unfiltered air from emergence through harvest, a period of 43 days, and the tomato plants were exposed for 93 days beginning 6 days after transplantation.

When most of the bean pods were mature, all were harvested by row and separated into two classes: marketable ($\geqslant$10 cm long with developing seeds) and unmarketable ($<$10 cm long and/or without developing seeds). The number and fresh weight of pods in each class were determined. The vegetative portions of bean plants were clipped at the soil level and divided into leaf and stem (including petioles and rachises) fractions and the dry weight of each fraction from each row was determined.

Tomato plants were pruned throughout the experiment to maintain single-stemmed plants, and the height of plants, from the soil surface to the base of the terminal shoot, was measured 99 days after transplantation. Harvests of ripe fruits at 3- or 4-day intervals began 58 days after transplantation and continued for 42 days. At that time (99 days after transplantation) when the danger of frost was imminent, all fruits regardless of maturity were harvested. After harvest, all ripe fruits were counted and weighed, cut in half at the equator, and the number of seeds and locules per fruit were counted.

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[2]Plant Physiologist and Research Associate, respectively.

RESULTS AND DISCUSSION

Oxidant Measurements

The concentrations of photochemical oxidants in the chambers over the course of the experiment have been characterized in three ways: (i) curves showing the average hourly concentrations in filtered and unfiltered chambers (Fig. 1); (ii) the average daily concentrations and the range of average daily concentrations for the exposure periods of both bean (43 days) and tomato (93 days) plants (Table 1); and (iii) a histogram showing the frequency distribution of mean hourly concentrations (Fig. 2).

Ozone is usually the major constituent of the photochemical oxidant complex (16, 23, 26). During the exposure periods for bean and tomato plants, O_3 probably accounted for almost all of the oxidant monitored during the daytime (about 0600–2100 hours) in unfiltered chambers. Simultaneous air analyses using both the coulometric method, which measures the total oxidant concentration, and the chemiluminescence method, which is specific for O_3, gave essentially identical results for the several periods when this was done. The absence of epinasty in tomato, and the fact that charcoal is a poor adsorbant of ethylene indicate that ethylene was not a contributing factor for the differences in plant responses between filtered and unfiltered chambers (1).

The ambient photochemical oxidant concentrations were closely related to the intensity of solar radiation. On sunny days, oxidant concentrations increased after dawn, peaked in midafternoon, and decreased in the evening; on overcast or rainy days, no appreciable peaks occurred and the oxidant concentrations were relatively low. The average hourly concentrations monitored in unfiltered chambers over the entire 99-day exposure period (mid-July to late Oct.) conformed to this characteristic diurnal pattern (Fig. 1).

The bean and tomato plants grown in unfiltered air were exposed to relatively high concentrations of ambient pollutants. The highest concentrations of photochemical oxidants in ambient air monitored at Yonkers, New York over a 6-year period (1969–1974) occurred during the summer months of 1973 while this experiment was under-

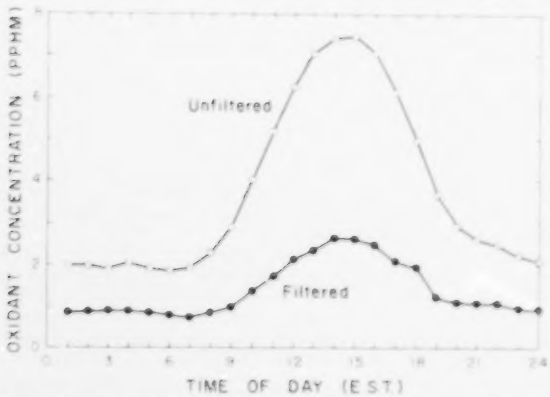

Fig. 1–Average hourly oxidant concentrations in charcoal-filtered and unfiltered chambers over the entire experimental period.

Table 1–Summary of average daily photochemical oxidant concentrations in chambers providing unfiltered and charcoal-filtered air for the durations of exposure of bean (43 days) and tomato (99 days) plants

Plant	Treatment	Daily oxidant concentrations	
		Average	Range
		pphm	
Bean	Filtered	1.22	0.55–2.70
	Unfiltered	4.13	1.70–9.00
Tomato	Filtered	1.49	0.75–2.88
	Unfiltered	3.52	1.68–7.18

way. During the 99-day experimental period, the U. S. air quality standard for photochemical oxidants (8 parts per hundred million [pphm] or 160 $\mu g \cdot m^{-3}$ for a 1-hour average) was exceeded 11% of the time. In filtered chambers this standard was exceeded for only one hour (8.4 pphm). The oxidant concentrations in the charcoal-filtered chambers were usually 60 to 70% less than in the unfiltered chambers. The average daily concentrations during the 43-day exposures of bean plants were 1.22 and 4.13 pphm in the filtered and unfiltered chambers, respectively; for the 99-day exposures of tomato plants, the average daily values were 1.49 and 3.52 pphm (Table 1).

The range of hourly oxidant concentrations in unfiltered chambers (Fig. 2) was from 0 to 20 pphm with the greatest proportion in the range of 0.5 to 3.4 pphm (about 65% of the time). Concentrations in this range may be considered as background because they occurred at night and on rainy or overcast days. Highly phytotoxic peak concentrations (≥ 10 pphm) occurred for 125 hours (about 6% of the time) over the 99-day exposure period.

Bean

Oxidant-induced foliar injury in unfiltered chambers was noted on unifoliate leaves 7 to 10 days after emergence. The initial symptoms were premature senescence (yellowing) and a mild, reddish-brown necrotic stipple on the upper surfaces of leaves that became more pronounced and extensive with time. By 20 days after emergence, in-

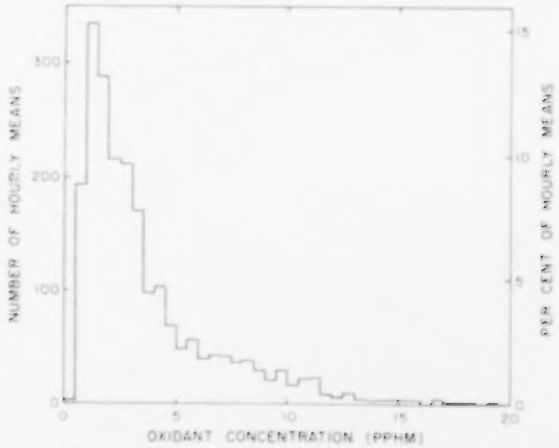

Fig. 2–Frequency distribution of mean hourly oxidant concentrations in unfiltered chambers as hours or percentage of the time at each concentration interval (0.5 pphm).

Table 2–Effect of ambient photochemical oxidants on the yield and dry matter of Tendergreen bean plants

Variable measured	Chambers providing: Carbon-filtered air*	Unfiltered air	Outside plots†
Number of pods harvested	88.4**	70.0	69.0
Number of marketable pods	70.4**	53.5	49.0
Number of unmarketable pods	18.0	16.5	20.0
Fresh weight of pods harvested, g	424.9**	320.9	283.5
Fresh weight of marketable pods, g	390.6**	288.6	243.6
Fresh weight of unmarketable pods, g	34.3	32.3	40.1
Dry weight of tops, g	80.9**	65.6	46.4
Dry weight of leaves, g	41.5*	35.2	26.5
Dry weight of stems, g	39.4*	30.4	20.1

* Differences between values from carbon-filtered and unfiltered air are for $\alpha = 0.05$ (*) and $\alpha = 0.01$ (**).
† Data from the outside plots were not included in the analysis of variance.

jury to unifoliate leaves was severe: many had abscised and in those remaining, the reddish-brown lesions were bifacial, larger, and covered most of the foliar surfaces. Injury to the oldest trifoliate leaves at that time was similar to that of unifoliate leaves 7 to 10 days after emergence. The appearance of foliar symptoms and their distribution on the plant closely resembled those produced in controlled fumigations of bean with O_3 (12, 13, 30), but were not like those induced by PAN (27) or NO_2 (18, 27). In chambers providing filtered air, oxidant-induced foliar injury was very mild and was limited to the unifoliate leaves. No symptoms were noted on pods in any treatments.

The growth (dry weight) and yield of bean plants in the unenclosed plots was consistently less than that of plants in unfiltered chambers (Table 2). However, the data for growth and yield from the unenclosed plots were not included in the statistical analyses because some of the plants had been destroyed by wildlife. Statistical analyses for growth and yield, therefore, were limited to comparisons between charcoal-filtered and unfiltered chambers.

The yield of all pods harvested from plants grown in unfiltered air was 20–25% less than for plants grown in filtered air (Table 2). The number and fresh weight of marketable pods in chambers that received unfiltered air were reduced by 24 and 26%, respectively. Vegetative growth as indicated by the dry weights of leaves and stems, was also significantly reduced in unfiltered chambers relative to filtered chambers. The dry weight of plant tops was reduced by 19%, with the reduction in the weight of stems (23%) exceeding that of leaves (15%).

Tomato

Leaves of tomato plants grown in unfiltered chambers showed moderate oxidant-induced injury 2 weeks after transplanting. This foliar injury became more extensive and severe with time. The oldest leaves became senescent, exhibited dark-colored stippling, and abscised prematurely. At the end of the experiment, only those leaves from nodes on the apical one-third of plants remained, and most of these were chlorotic. As noted above for bean, these symptoms on tomato were identical to O_3-induced

Table 3–Effect of ambient photochemical oxidants on various parameters of fruit production and growth of Fireball tomato plants

Variable measured	Charcoal-filtered air	Unfiltered air
Fresh weight of ripe fruit, g	750.4	497.3*
Number of ripe fruit/plant	9.4	7.1
Total number of fruit/plant†	20.6	15.4
Fresh weight/ripe fruit, g	81.7	70.6
Number of seeds/ripe fruit	60.6	54.8
Number of locules/ripe fruit	5.4	4.9
Plant height, cm	89.4	90.9

* Significantly less than corresponding value for charcoal-filtered air ($\alpha = 0.01$).
† Includes ripe fruit and all immature fruit picked at end of experiment.

foliar injury (5, 12, 13, 22), and atypical of symptoms induced by PAN (27) or NO_2 (18, 27). Leaves on plants in the filtered chambers remained green longer and at the end of the experiment one-half to three-fourths of the leaves remained. Elongation of the single-stemmed plants was the same in filtered and unfiltered air (Table 3).

The cumulative yield of tomato fruits, as both fresh weight and number, was identical in both filtered and unfiltered air until 84 days after transplantation; thereafter, the cumulative yields from unfiltered chambers lagged behind the yields from plants in filtered chambers (Fig. 3). After the 99-day exposure, the cumulative yields of tomato fruits, as mass, revealed a 33% reduction for plants grown in unfiltered chambers relative to charcoal-filtered chambers: 750.4 and 497.3 g per plant from

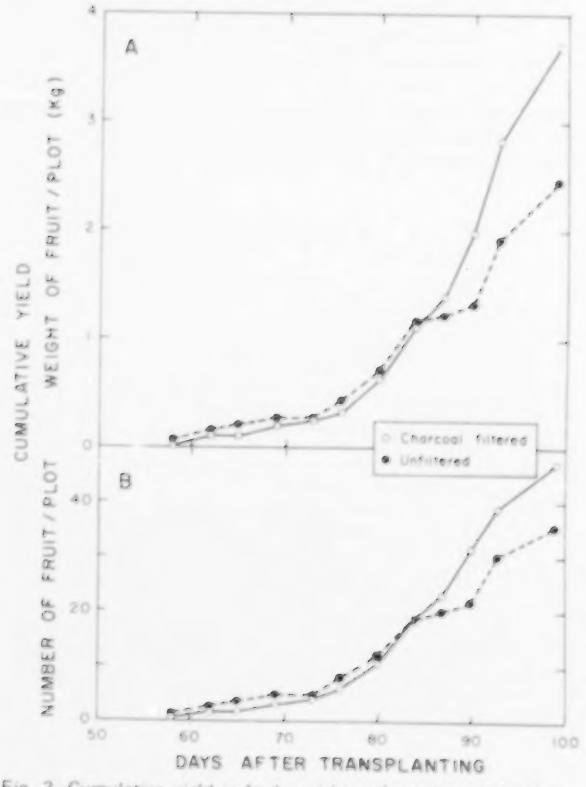

Fig. 3–Cumulative yield as fresh weight and number of ripe fruit harvested from Fireball tomato plants grown in charcoal-filtered and unfiltered air.

filtered and unfiltered chambers, respectively (Table 3). However, the number of ripe fruits produced per plant and the average size (weight) of those fruits were not significantly affected by treatment. When the immature fruits harvested at the end of the experimental period were included with ripe fruits, the statistical analysis showed that there was no difference due to treatment in the total number of fruits produced. Inspections of ripe fruit showed that the general appearance and the number of locules and seeds per fruit were not affected by ambient oxidants (Table 3).

CONCLUSIONS

We conclude that the observed reductions in yield and the increases in the incidence and severity of leaf injury in bean and tomato plants grown in unfiltered air relative to charcoal-filtered air were due to the elevated concentrations of photochemical oxidants in unfiltered chambers. We further conclude, based upon air measurements and the type and pattern of foliar symptoms, that O_3 was the oxidant primarily responsible for these effects.

If the atmospheric concentrations of ambient oxidants do not exceed the U. S. air quality standard, reductions in yield would probably not be serious, or would not occur. However, concentrations that exceed the standard, such as those monitored in Yonkers (Westchester County), New York in 1973, very likely result in reductions in yield in many crops of the northeastern United States. The bean and tomato cultivars used in this study were not selected for their extreme susceptibility to oxidants: they are only moderately susceptible relative to other cultivars of the same species (4, 5, 7, 10). Nevertheless, the magnitude of the reductions in yield found for bean and tomato illustrates dramatically the serious economic consequences of ambient photochemical oxidants.

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